

Session 4: Emerging Technologies



Dr. Timothy Rials

- University of Tennessee of Agriculture-
- Director of Center for Renewable Carbon-





CRC

Center for Renewable Carbon

 University of Tennessee Institute of Agriculture

T.G. Rials, Director

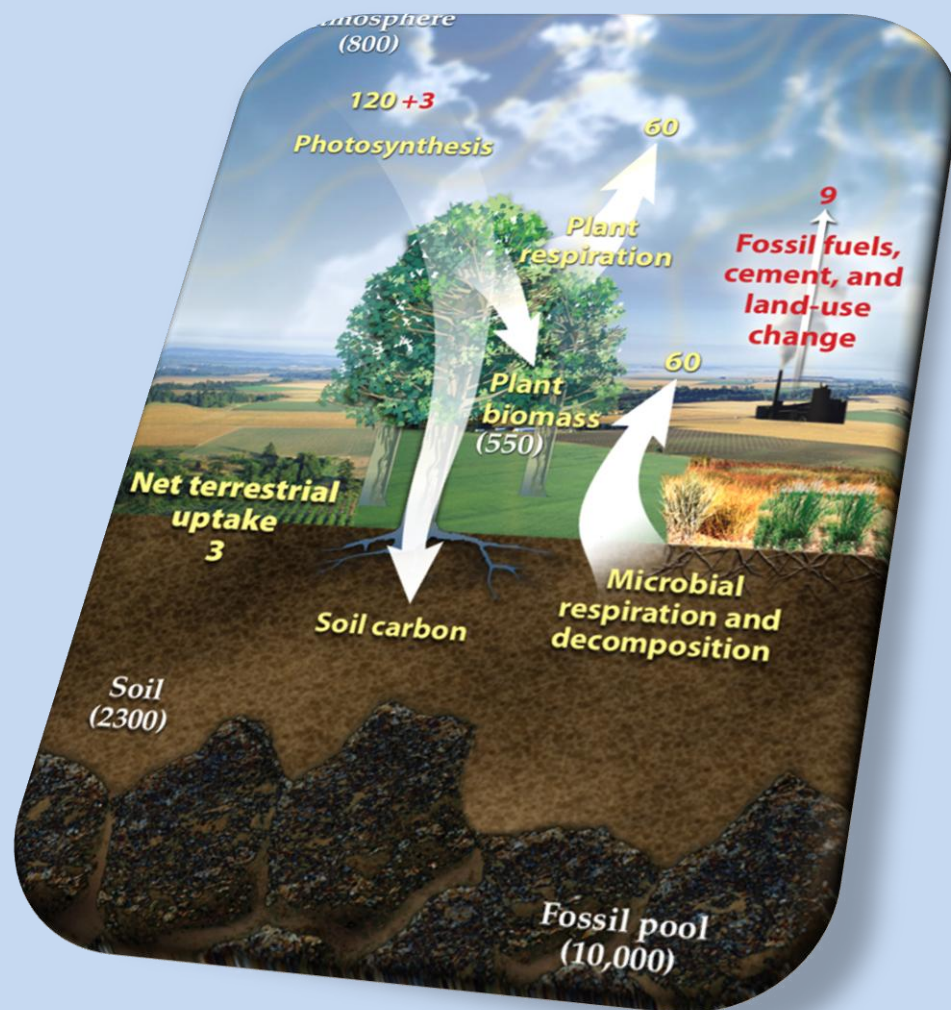
The University of Tennessee
Institute of Agriculture
2506 Jacob Drive
Knoxville, TN 37996-4570

www.UTBioenergy.org

It's A New Day...

Renewable Carbon

- The structural biomass (non-food) component produced from photosynthesis - lignocellulose
- Traditionally sourced for materials applications
- Expanded emphasis on energy, fuels, and chemicals
- Accelerated convergence of agricultural and forest sectors
- Emerging new toolbox for carbon management



A Multi-Faceted Mission...

- Coordinate UTIA's renewable carbon systems R&D
- Innovate in process technology producing fuels, materials, and chemicals from renewable carbon
- Support production and conversion system demonstrations
- Educate and train the new workforce
- Transfer knowledge on renewable carbon technologies to a broad client base



Structure and Capacity...

- The Forest Products Center expands research leadership role as Center for Renewable Carbon
- Continue programmatic emphasis on wood materials
- Bioenergy Science and Technology (BeST) Lab – occupancy scheduled for October 2010
- State-of-the-art instrumentation through partnership with Perkin-Elmer Life Sciences



Current CRC Programs

UT Biofuels Initiative

- Tennessee funded program to demonstrate the technical and economic feasibility of cellulosic fuels; involves a partnership between UT, Genera Energy, and DuPont-Danisco Cellulosic Ethanol (DDCE)

The Sun Grant Initiative

- Multi-faceted program to accelerate development of alternative energy from renewable carbon sources that is administered by Oregon State Univ., SD State Univ., Oklahoma State Univ., Cornell, and Univ. of Tennessee. Partner agencies include DOT, DOE, and USDA.

Wood Utilization Research Grant

- USDA sponsored program to support research and development innovations in wood and related material systems to improve the competitive position of the forest products industry. The program is conducted by 14 land-grant universities across the nation.

Bioenergy Production and Carbon Cycling

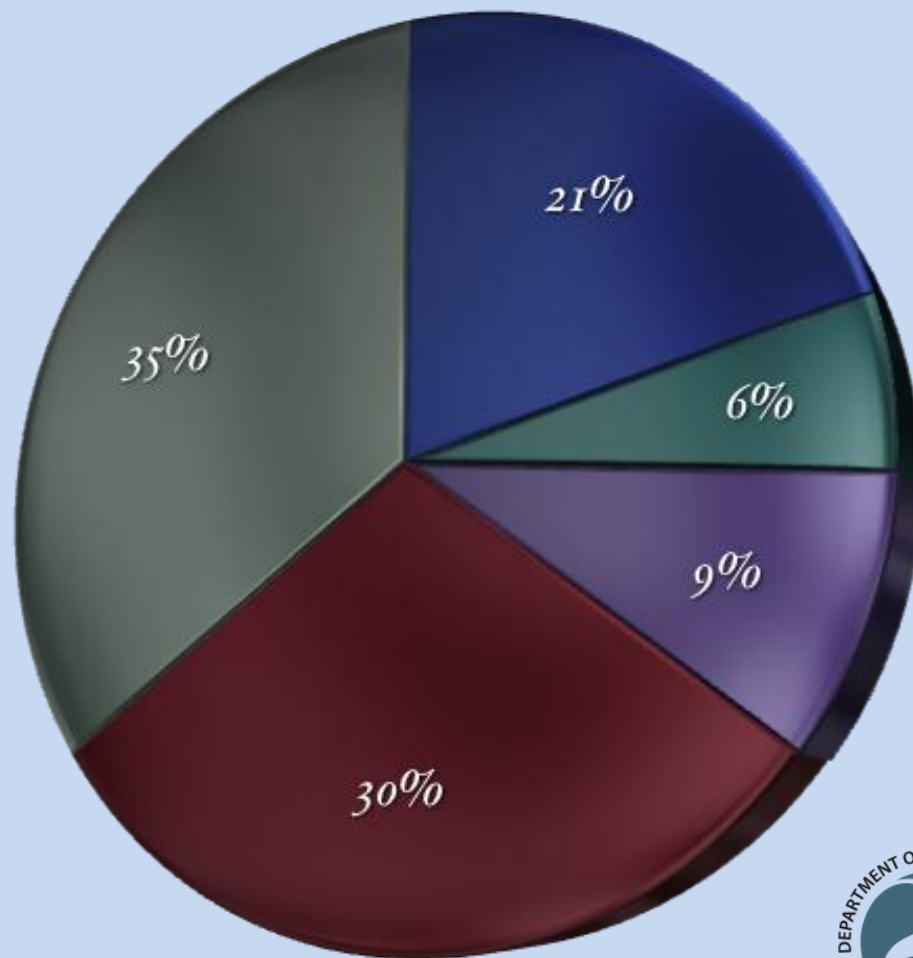
- USDA sponsored program to assess the effect of land-use history on soil carbon sequestration and below-ground ecology of switchgrass production. Also, the impact of biochar from different sources on productivity are under investigation.



The Sun Grant Center

Topic Area Distribution

- New Crop Development
- Sustainable Production
- System Logistics
- Feedstock Preparation
- Conversion Technology



- Portfolio of \$4.25 M in projects across the southeast region's land-grant universities (RFP's in 2007 and 2009).
- Additional RFP under development for January 2011 release.



Regional Feedstock Partnership

Feedstock Categories



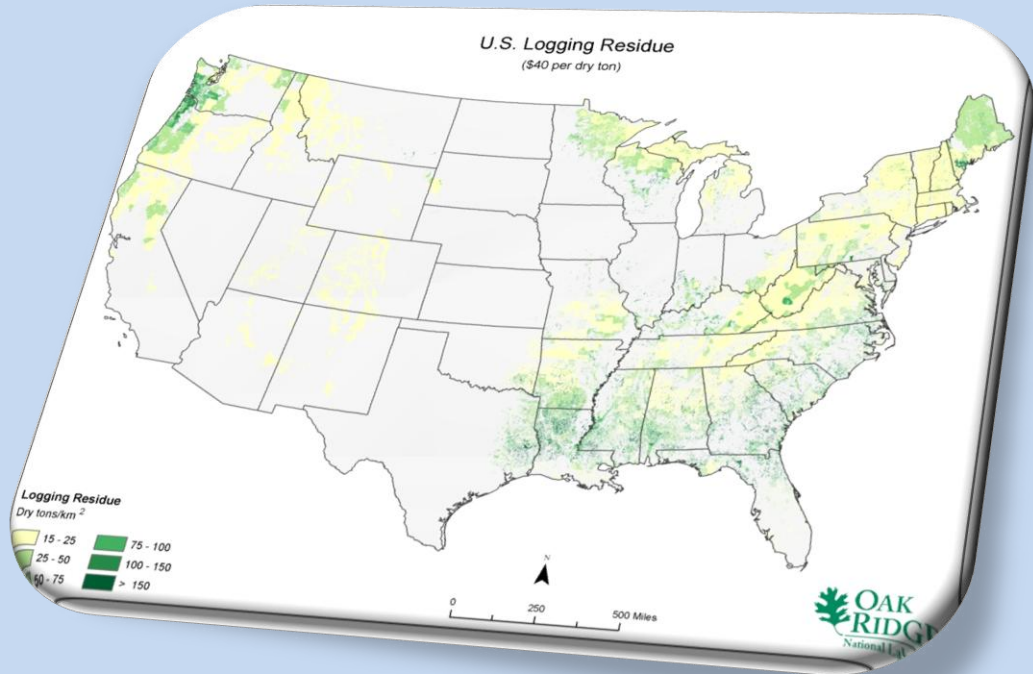
Targeting New Information Needs

POLYSYS – FOR

- POLYSYS is the standard bearer land-use allocation model in the agricultural sector
- Introduced new module to consider agricultural and forest biomass...simultaneously
- Allows for apples-to-apples analysis of biomass production from both sectors
- Lead – Dr. Burt English

BioSAT

- New biorefinery site evaluation tool that incorporates agricultural and forest biomass
- Emphasizes transportation network and resource competition
- Lead – Dr. Tim Young



The Biofuels Initiative

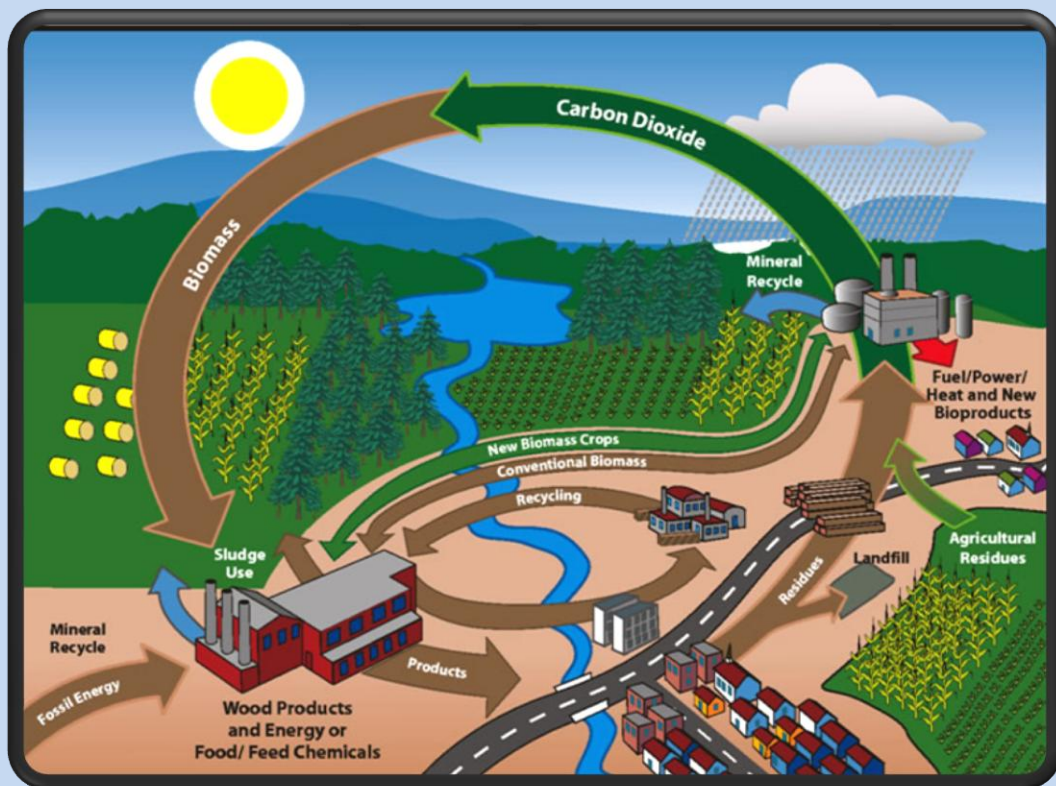
- ✓ Demonstrate cellulosic biofuels
- ✓ Develop a regional bioenergy crop
- ✓ Advance R&D capacity in biomass production and processing
- ✓ Establish a commercialization pathway for the state and region



2007 2008 2008 2009 2009 2009 2009 2010 2010 2010



The R&D Capability



- A unique laboratory setting
- A unique opportunity to resolve challenging barriers
- An obligation to fully utilize the resource
 - Engage appropriate skills
 - Maximize collaborative relationships
 - Draw on partnerships

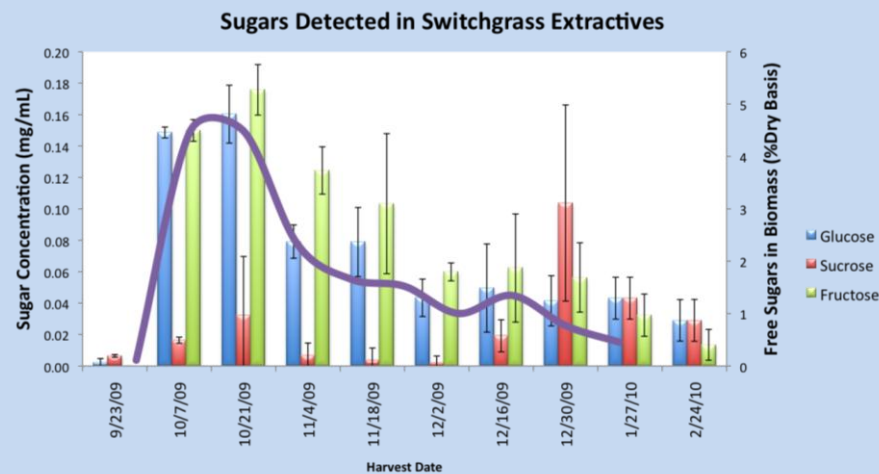
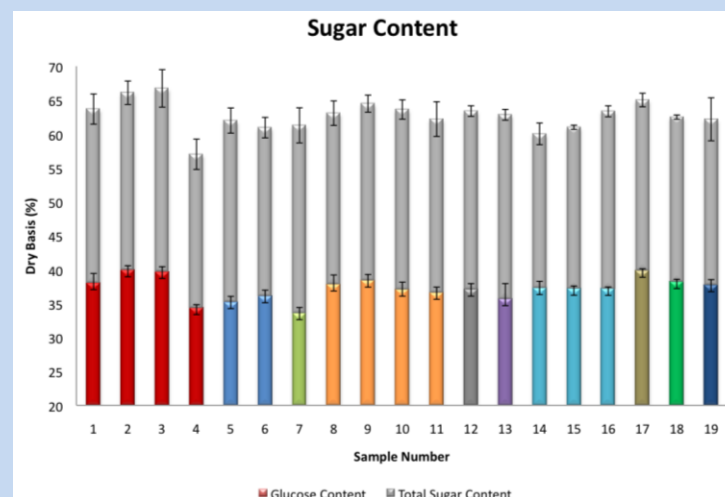
Providing Vital Information

- Environmental and ecological effects of switchgrass
 - *Partnering with CBES and ESD (ORNL)*
- Carbon sequestration in switchgrass ecosystems
 - *Interdisciplinary research team of engineers, economists, ecologists, chemists*
- Variability in feedstock quality – site, variety, and temporal effects
 - Process optimization insights for switchgrass



Providing Vital Information

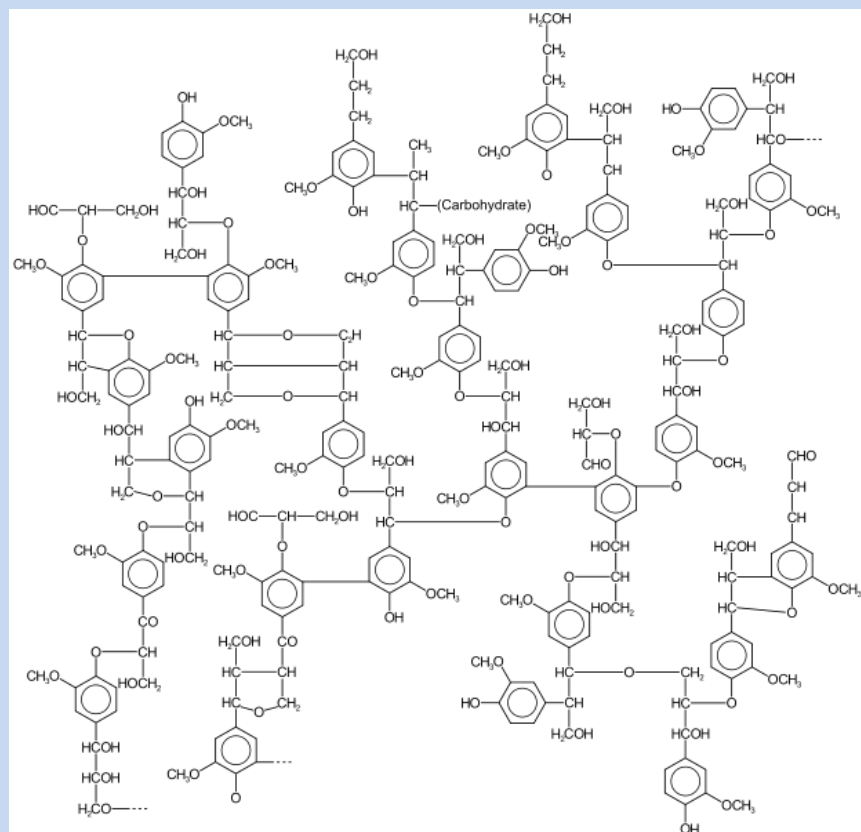
- Chemical composition varies slightly between sites, as well as location in the field
 - Directly related to product yield
- The amount of “free” sugars are impacted by time of harvest, declining dramatically from October to December
 - Present unique process challenges



Dr. N. Labbe, et al, 2010

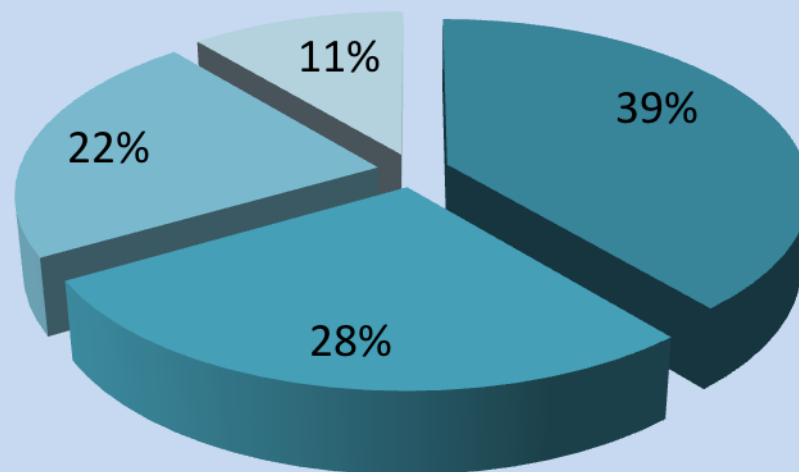


Cell Wall Constituents



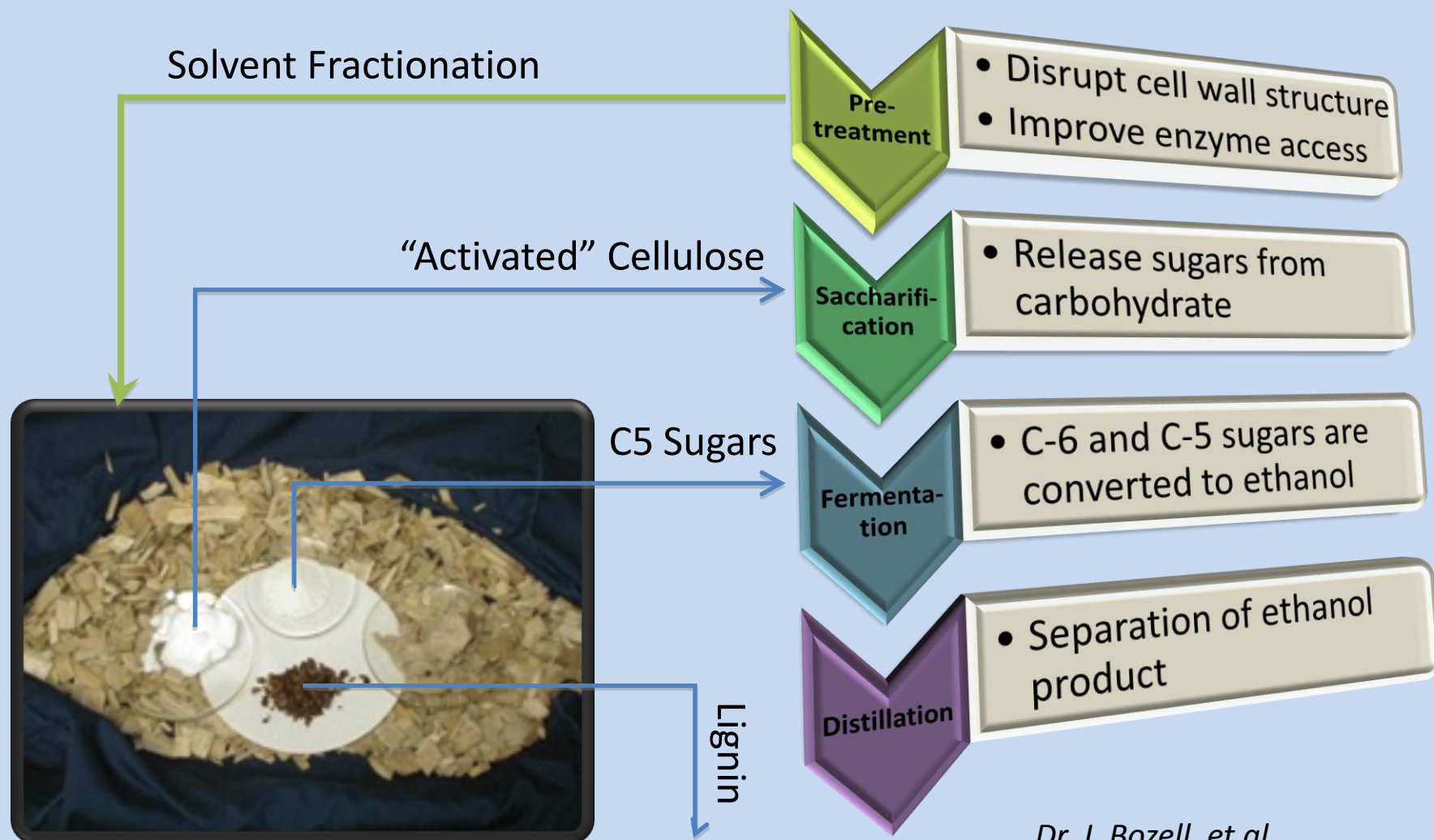
Typical lignin structure.

Switchgrass Chemical Composition



- Cellulose
- Hemicellulose
- Lignin
- Extractives

Biomass Fractionation

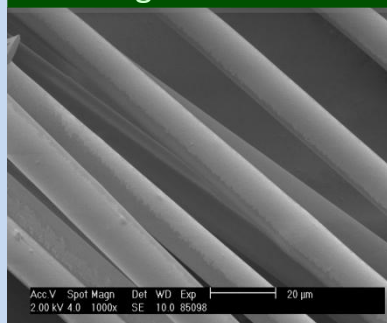


Dr. J. Bozell, et al

Innovative Coproducts...

High-strength,
light weight
composites
for various
markets

Lignin Fiber

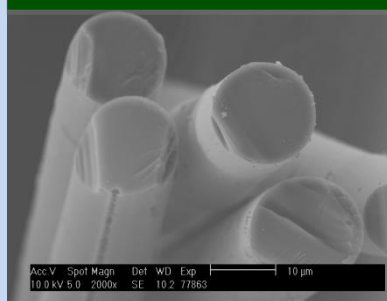


CNT's introduce
unique properties
for electronics



High surface
area for gas
storage (H_2)
applications

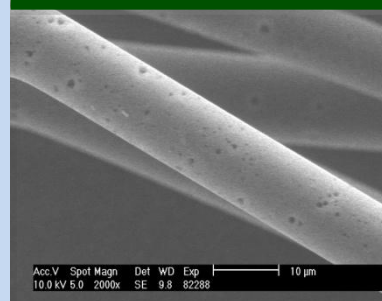
Carbon Fiber



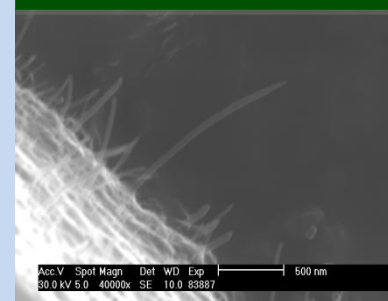
Value Added

Fuel = \$200/dt
Fiber = \$2000/dt

Porous Carbon Fiber



CNT Carbon Fiber



Dr. D. Baker and D. Harper



Concluding Remarks

- The Center for Renewable Carbon brings a new perspective and scope to bioenergy R&D
- The CRC relies on interdisciplinary approaches to address complex questions and barriers
- The CRC provides for near-term information needs, and provides direction for long-term systems innovation
-



Thank You!



Center for Renewable Carbon

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-Oak Ridge National Laboratory-

-Director of Bioenergy Science Center-



BioEnergy Science Center: An Integrated Strategy to Understand Biomass Recalcitrance



Presented at the:

**Tennessee Alternative Fuels and
Bioenergy Conference**

August 15-17, 2010

**Paul Gilna, Director
BioEnergy Science Center**



BioEnergy Science Center

An Integrated Strategy to Understand Biomass Recalcitrance

BESC: A multi-institutional
DOE-funded center

Samuel Roberts Noble Foundation

National Renewable Energy
Laboratory

Brookhaven National Laboratory

University of California–Riverside

Cornell University

Washington State University

University of Minnesota

North Carolina State University

Virginia Polytechnic Institute

University of California–Los Angeles



Oak Ridge
National Laboratory

University of Georgia

University of Tennessee

Dartmouth College

Georgia Institute of Technology

West Virginia University

ArborGen, LLC

Ceres, Incorporated

Mascoma Corporation

Verenium Corporation

**322 People
in 20 Institutions**

It's about who and how (as well as what)



SCIENCE RETREAT DECEMBER 2008



SCIENCE RETREAT JUNE 2009



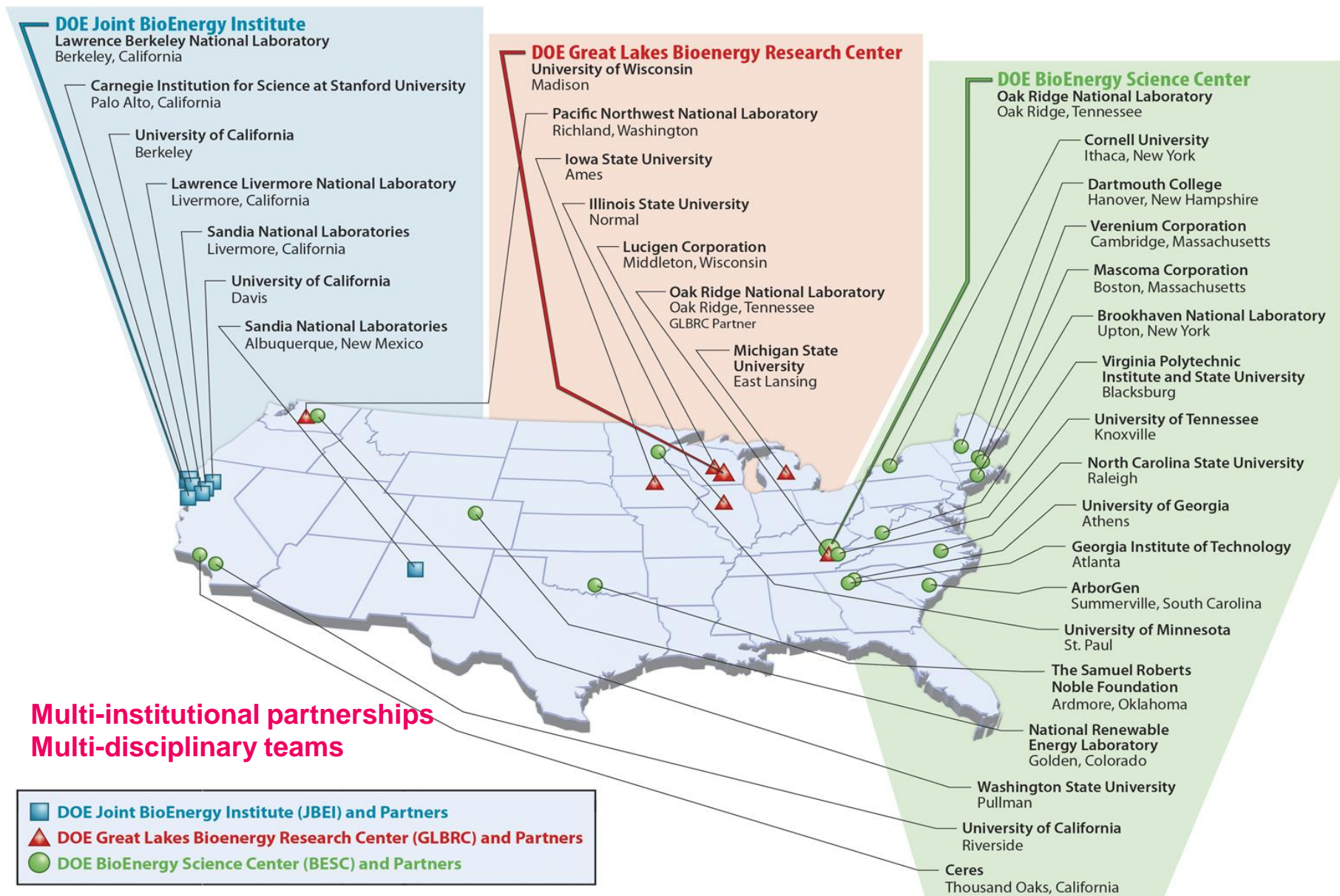
BESC is a U.S. Department of Energy Bioenergy Research Center supported by the Office of Biological and Environmental Research in the DOE Office of Science



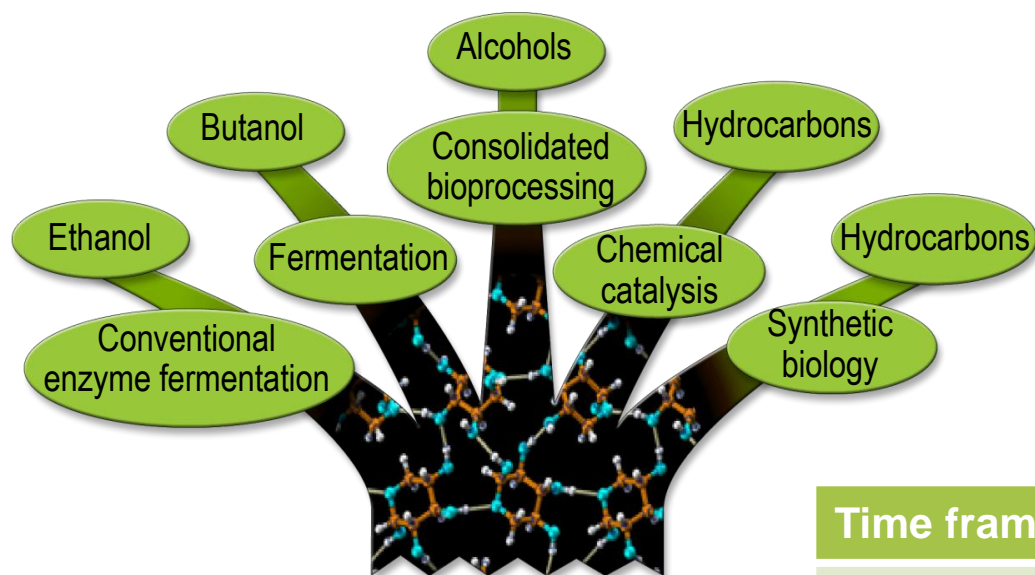


DOE Bioenergy Research Centers

3 BRCs launched in FY 2007 to pursue transformational science for new, sustainable biofuels



Access to the sugars in lignocellulosic biomass is the current critical barrier



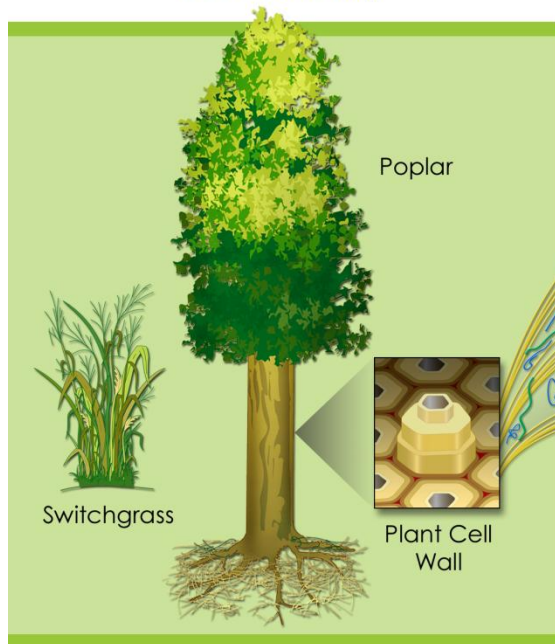
Recalcitrance

- Overcoming this barrier will cut processing costs significantly and be used in most conversion processes
- This requires an integrated multidisciplinary approach

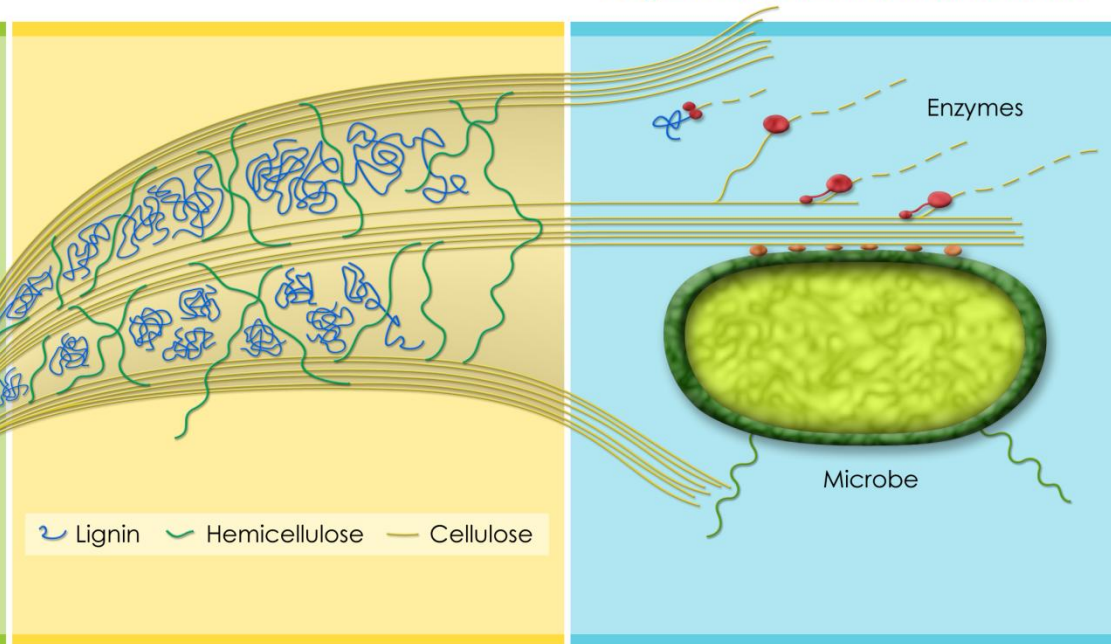
Time frame	Planned	Actual
Modified plants to field trials	Year 5	Year 4
New or improved microbes to development	Year 4–5	Year 3–4
Analysis and screening technologies	Year 3 on	Year 2 on

A two-pronged approach to increase the accessibility of biomass sugars

Modify the plant cell wall structure to increase accessibility



Improve combined microbial approaches that release sugars and ferment into fuels

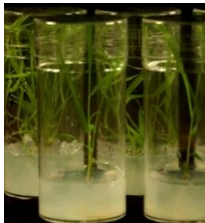
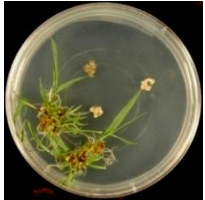
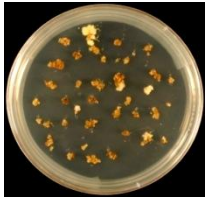


Both utilize rapid screening for relevant traits followed by detailed analysis of selected samples

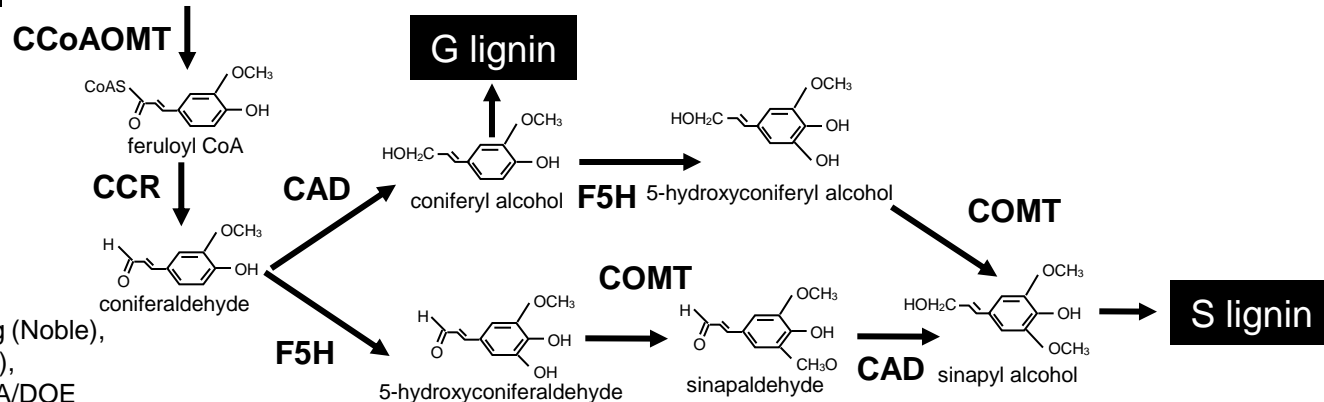
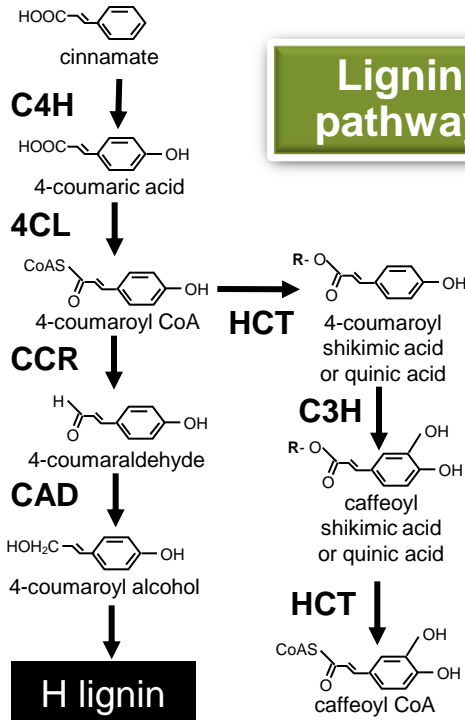
Genetic block in lignin biosynthesis in switchgrass increases ethanol yields

Phenylalanine → PAL

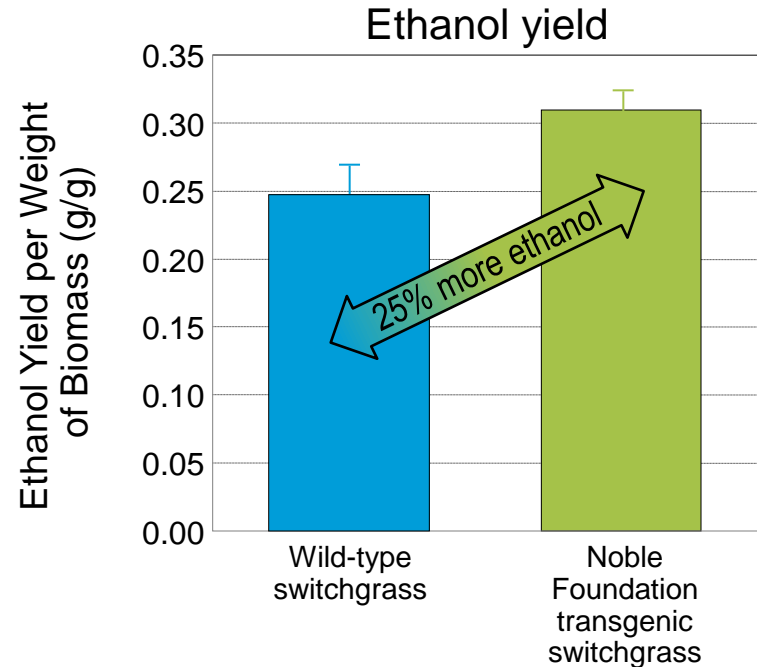
Agrobacterium-mediated transformation of switchgrass



THE SAMUEL ROBERTS
NOBLE
FOUNDATION



X. Fu and Z. Wang (Noble),
J. Mielenz (ORNL),
support from USDA/DOE



The BESC Transformation Pipeline (TP) is Fully Operational for BESC Plant Wall Mutants

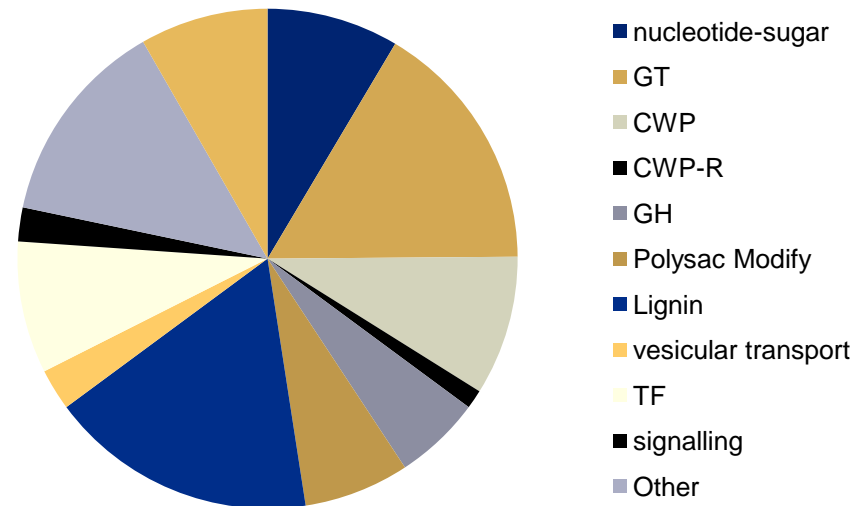
450 genes submitted to TP; 326 genes accepted

477 constructs accepted in TP:
(353 *Populus*, 124 Switchgrass/VIGs)

50 *Populus* construct lines sent to PIs: (1030 lines; ~10,000-20,000 plants)

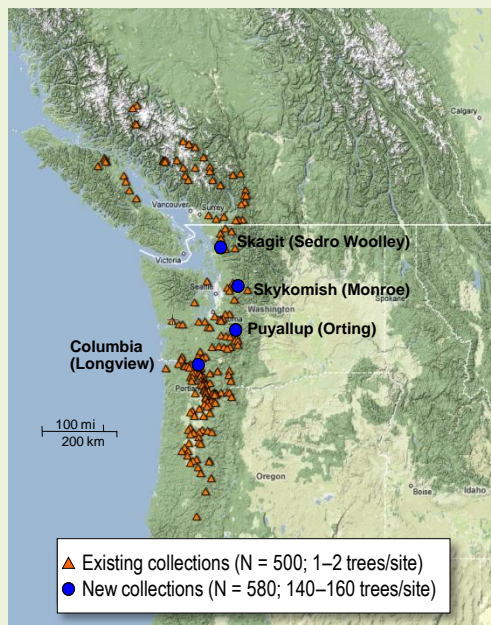
79 Virus Induced Gene Silenced (VIGs) (foxtail millet) Constructs

45 stable Switchgrass transformation



Mining variation to identify key genes in biomass composition and sugar release

Collected ~1300 samples for *Populus* association and activation-tag study



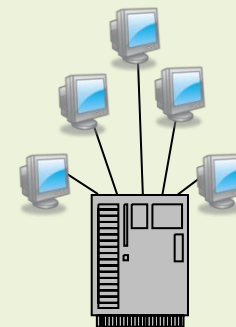
High-throughput screening pipeline

- Create genetic marker map to identify allelic variation
- Identify marker trait association



Sugar
release
assay

Cell wall biosynthesis database

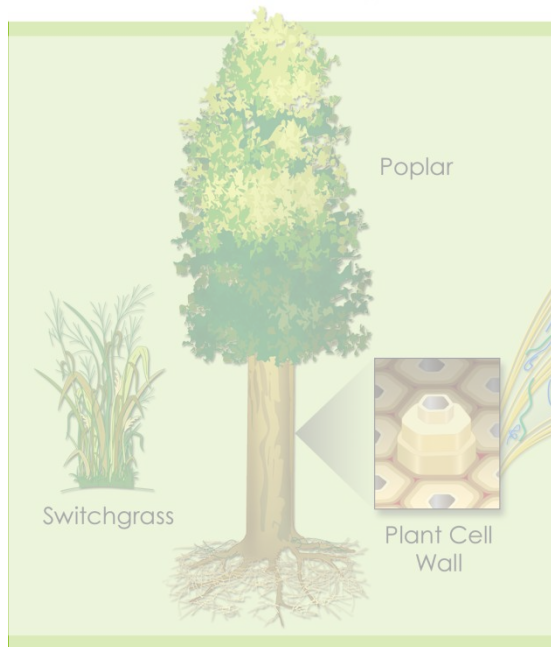


Establish common gardens for association and activation-tag populations with thousands of plants

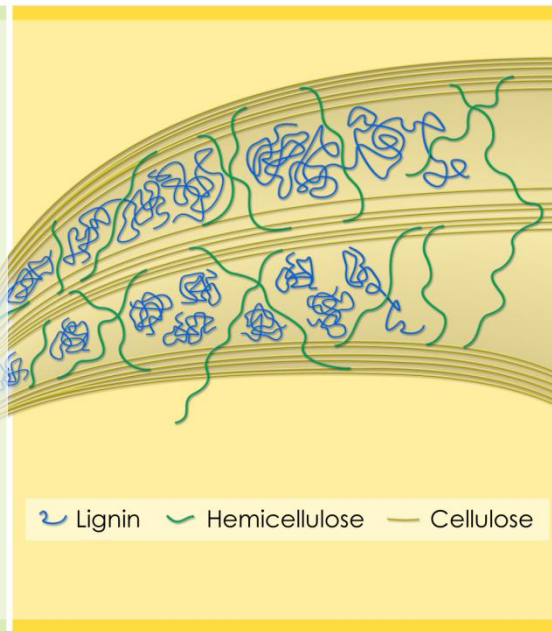


Strategy, part 2: Measure, understand, and model biomass recalcitrance

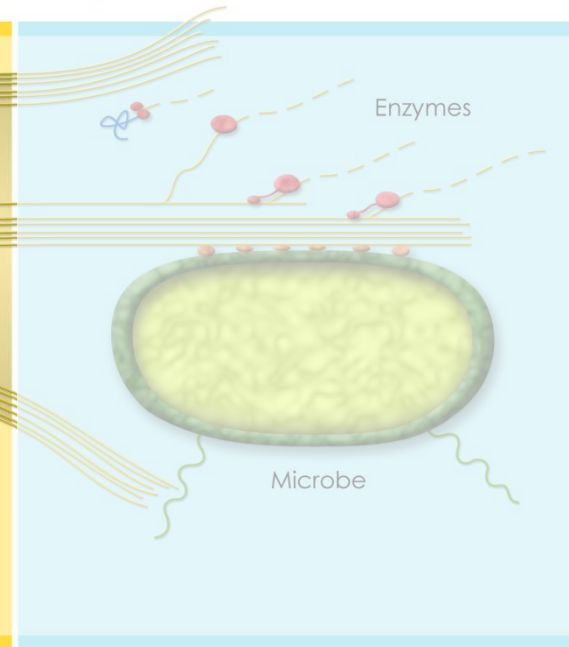
Biomass formation
and modification



**Characterization
and modeling**



Biomass deconstruction
and conversion



High-throughput characterization pipeline for the recalcitrance phenotype

Screening thousands of samples

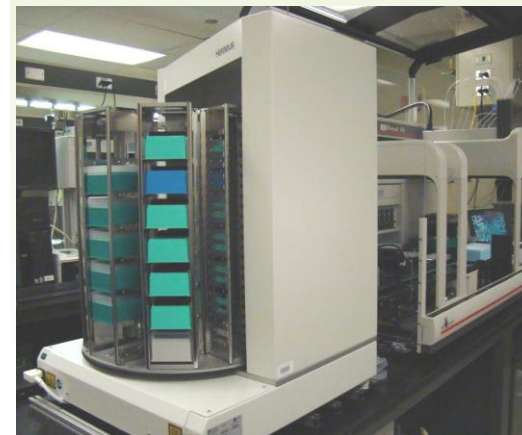
Composition analytical
pyrolysis, IR, confirmed
by wet chemistry



Pre-treatment
new method with dilute
acid and steam



Enzyme digestibility
sugar release
with enzyme cocktail



Detailed chemical and structural analyses of specific samples

The High-Throughput Pretreatment and Hydrolysis (HTPH) System has Analyzed >10,000 Samples for Composition and Digestibility

Table 1. Unique BESC samples submitted and analyzed by HTP pipelines (not including replicates).

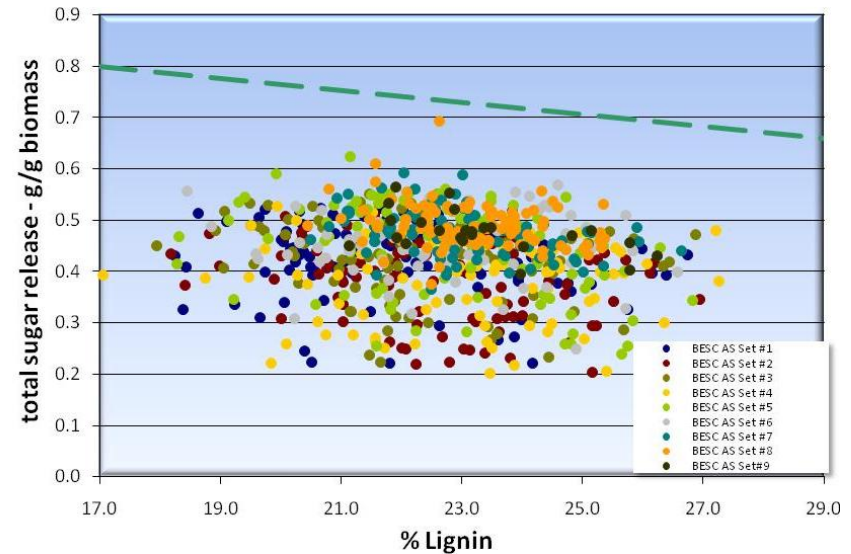
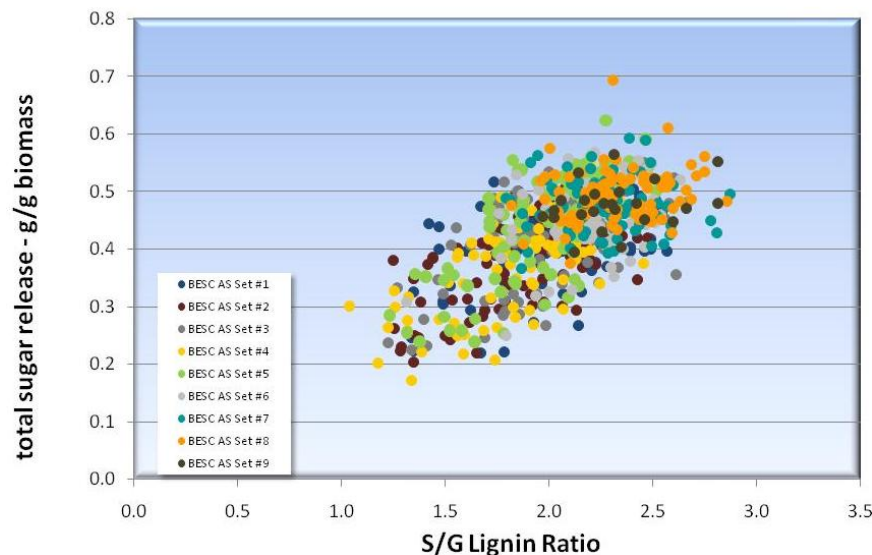
	CRCC	ORNL	UCR	Noble	U. Tennessee	Total
Analytical Pyrolysis	138	795	11	140	5248	6332
Recalcitrance	112	807		147	5248	6314

Table 2. Samples from Industrial, International, and external collaborations.

	ArborGen	Purdue	U. Copenhagen	Edenspace	Total
Analytical Pyrolysis	640	3000			3640
Recalcitrance	24	731	1100	120	1975

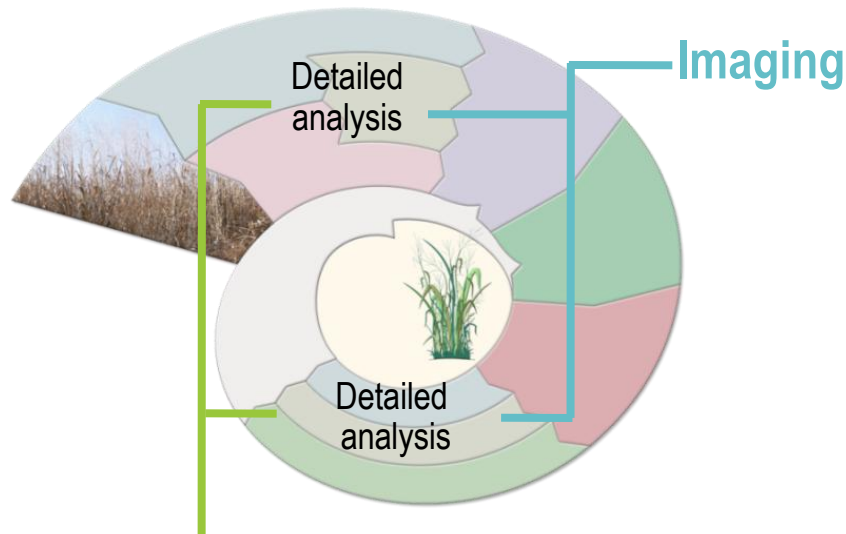
High-throughput screening to analyze natural *Populus* trees

- Screening of 1200 natural *Populus* trees
- Hot water as pretreatment only
- Sugar release varies from 25% to >90% of theoretical value



Environmental vs genetic?

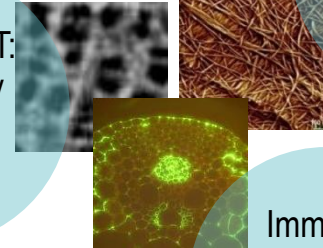
Detailed analysis of specific samples inform cell-wall chemistry and structure



AFM of
switchgrass
showing
cellulose
microfibrils



Bio-ultraCAT:
3-D density
of *Populus*
cell walls



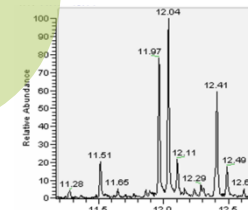
Immuno-
localization using
wall antibodies
on switchgrass



The University of Georgia

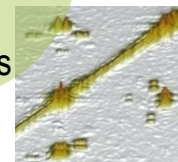


Mass
spectrometry
for key
metabolites

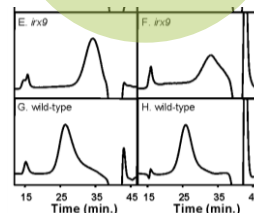


The University of Georgia

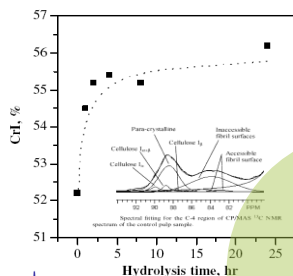
2D ^1H -NMR
sees altered
bonds in
polysaccharides
and lignin
in biomass



Fractionation
and
chromatography



Chemistry



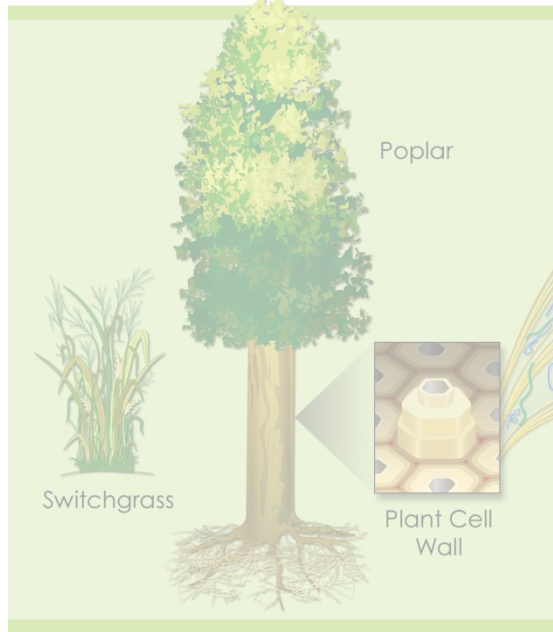
NMR for
cellulose
crystallinity



Strategy, part 3:

Identify, understand, and manipulate “biological catalysts” to overcome recalcitrance

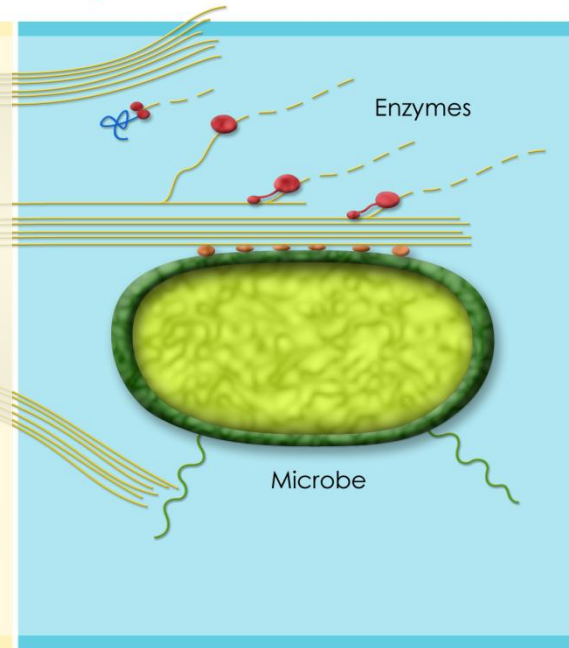
Biomass formation
and modification



Characterization
and modeling



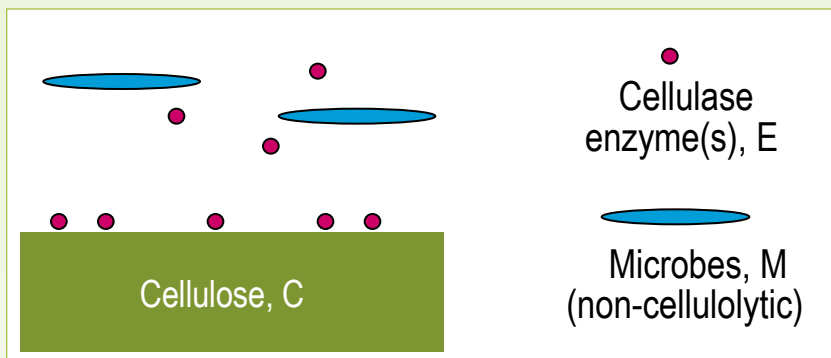
**Biomass deconstruction
and conversion**



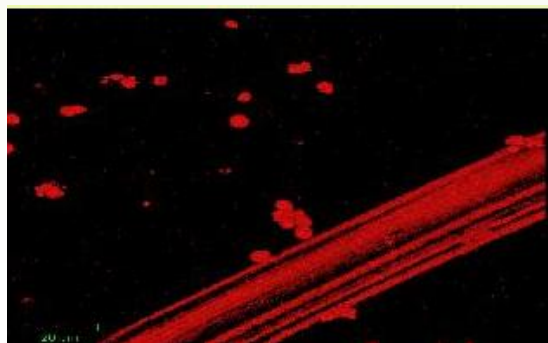
Enzymatic and microbial hydrolysis

A fundamentally different relationship between microbes and cellulose

Enzymatic hydrolysis (classical approach)

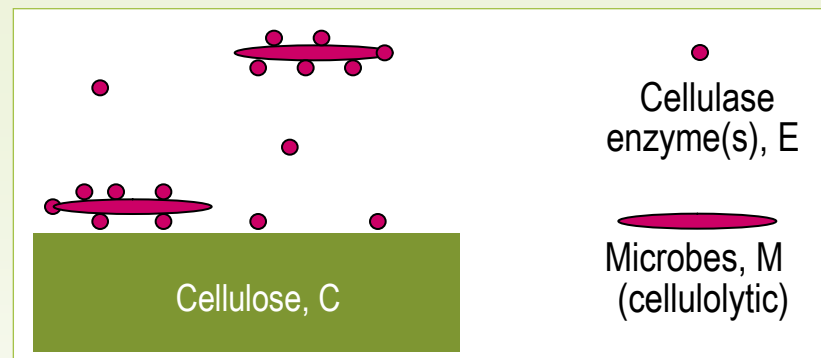


- Hydrolysis mediated by CE complexes
- Enzymes (several) both bound and free
- Cells may or may not be present

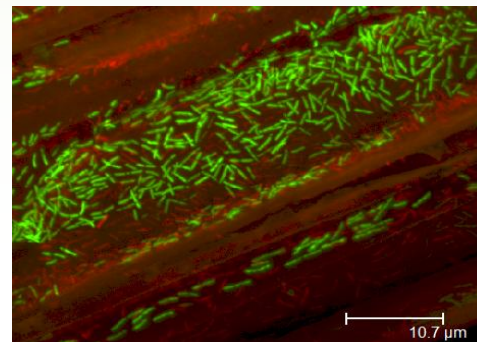


Yeast, enzymes
with biomass
(Dumitrache
and Wolfaardt)

Microbial hydrolysis (CBP)

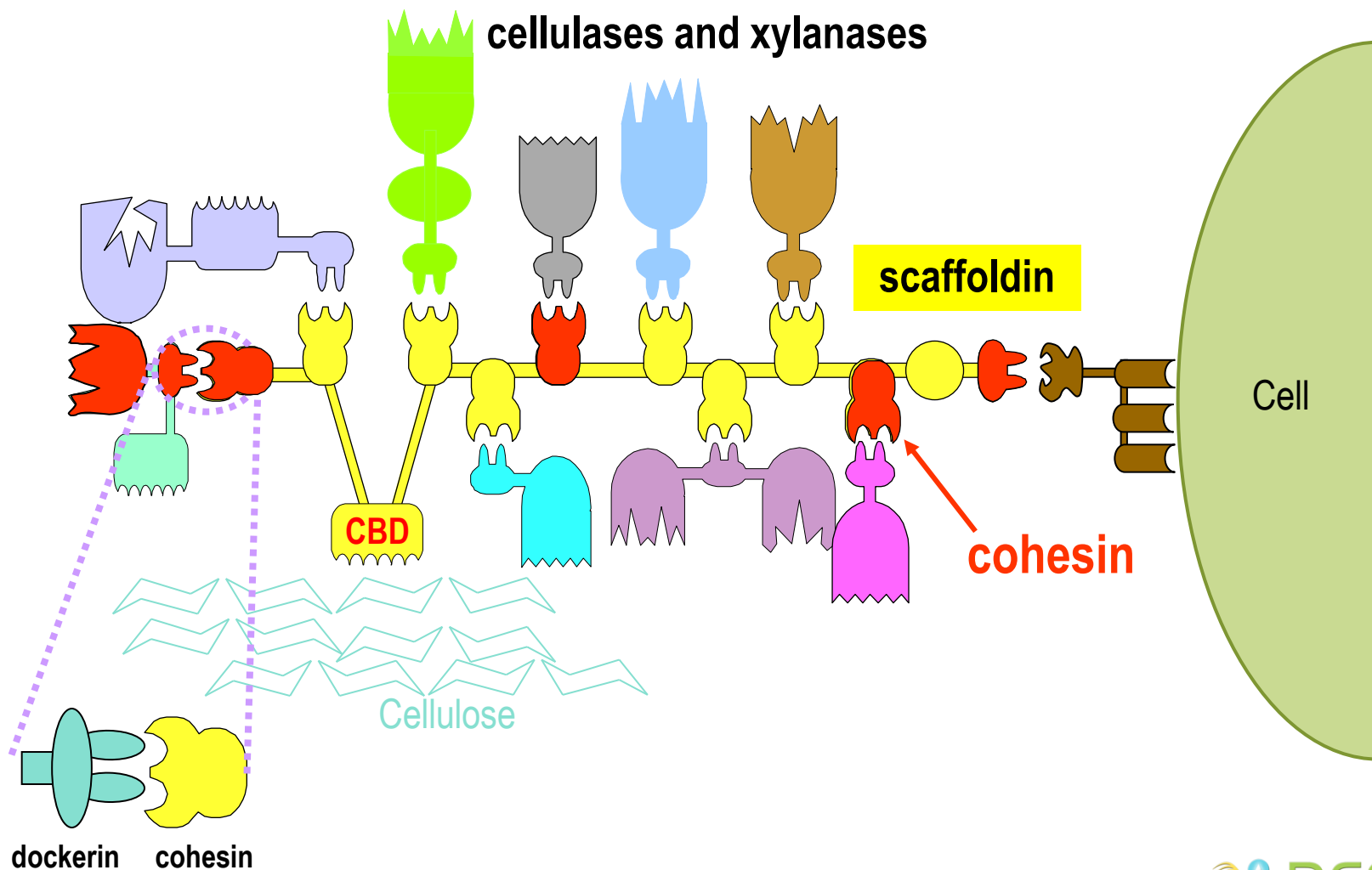


- Hydrolysis mediated mainly by CEM complexes
- Enzymes both bound and free
- Cells both bound and free

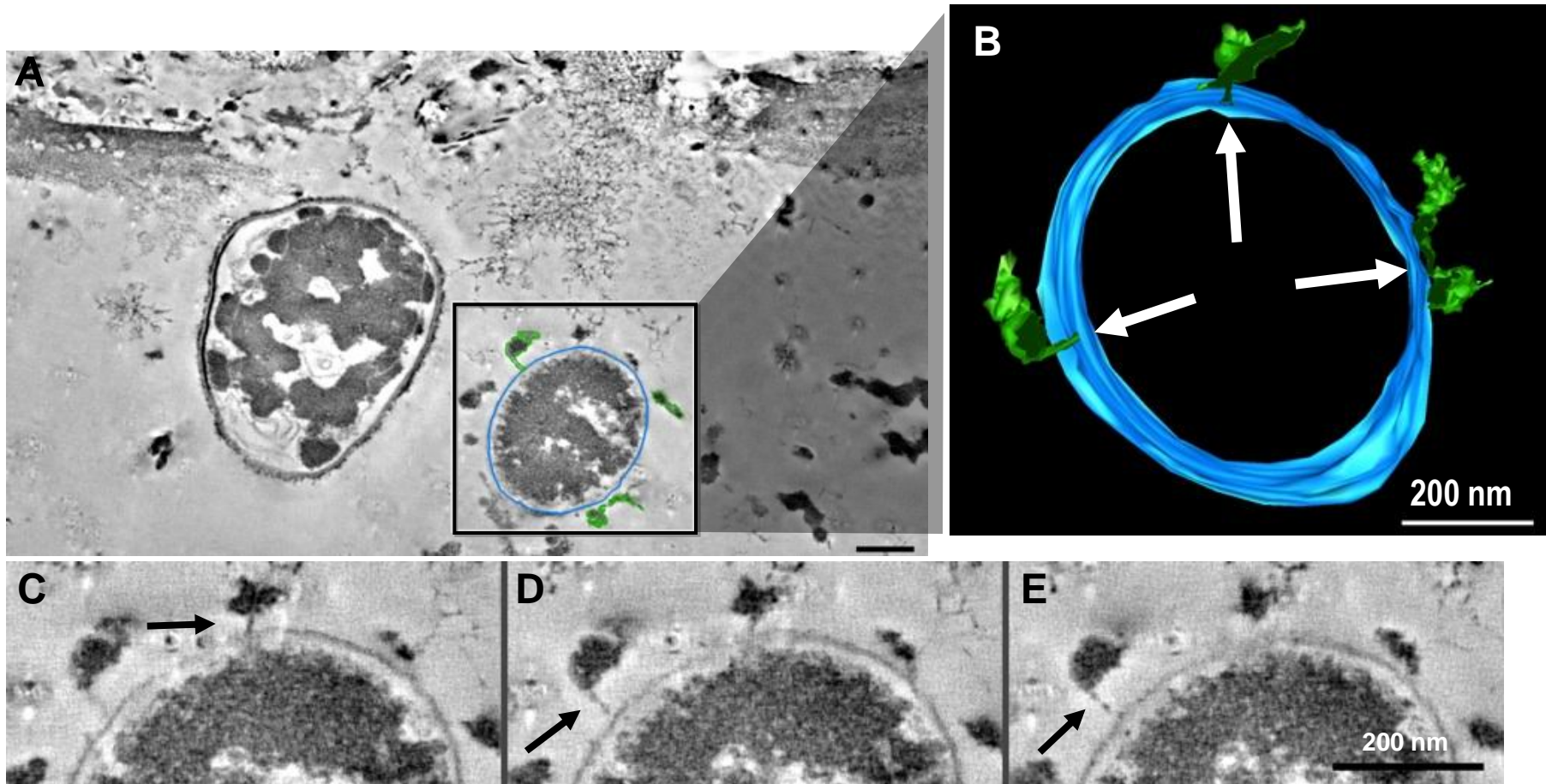


C. thermocellum
on poplar
(Morrell-Falvey
and Raman, ORNL)

Cellulosome of *C. thermocellum*

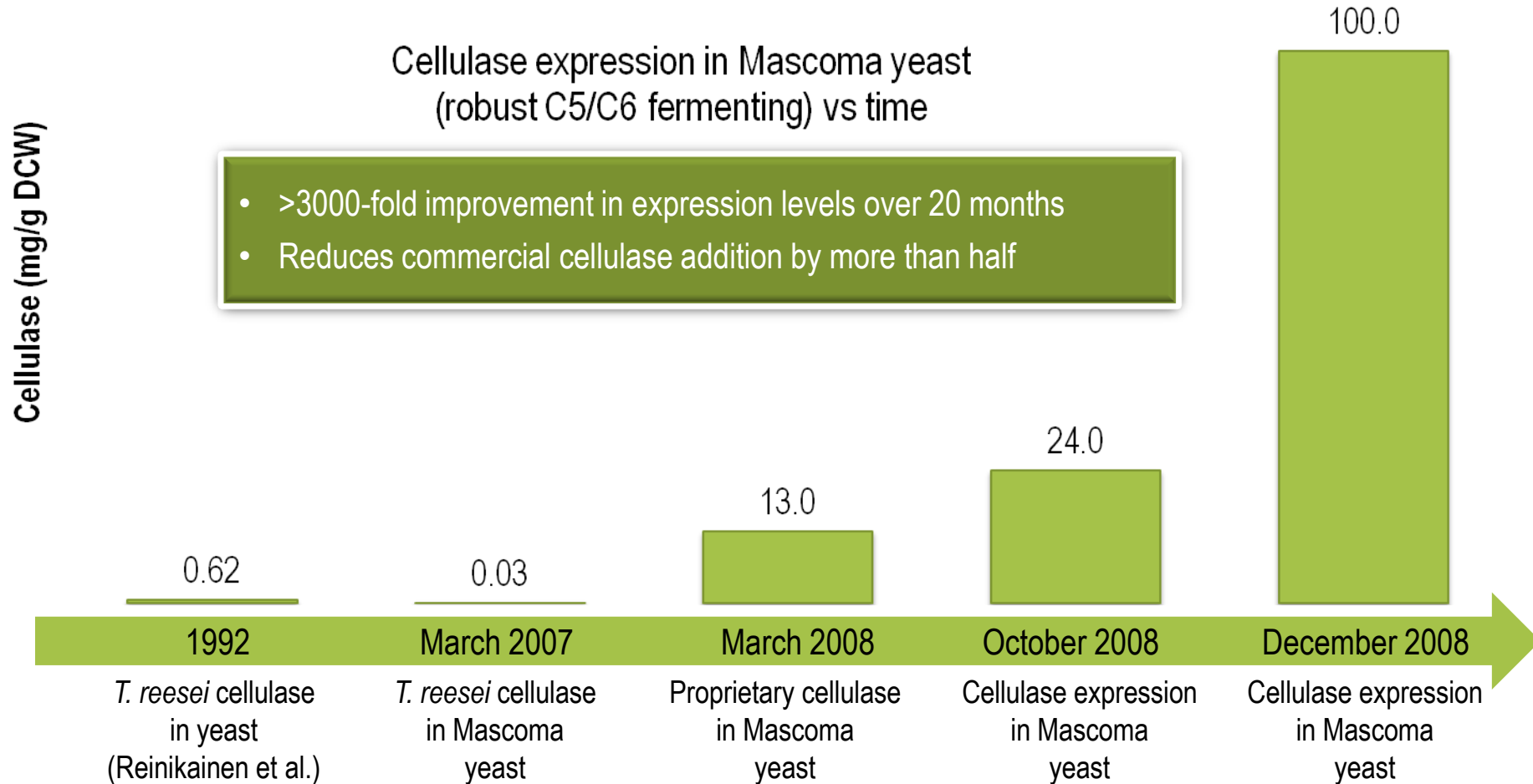


3D electron tomography of *C. cellulolyticum*



Tomogram slices and surface rendered segmentation of bacterial cells and tethered cellulosomes. C–E: Serial slices taken every ~8 nm through tethered cellulosomes. These tethers are seen at one end of most polycellulosomes found near the bacterial cell surface and are ~5 nm in diameter and up to 50 nm in length.

CBP organism development yeast

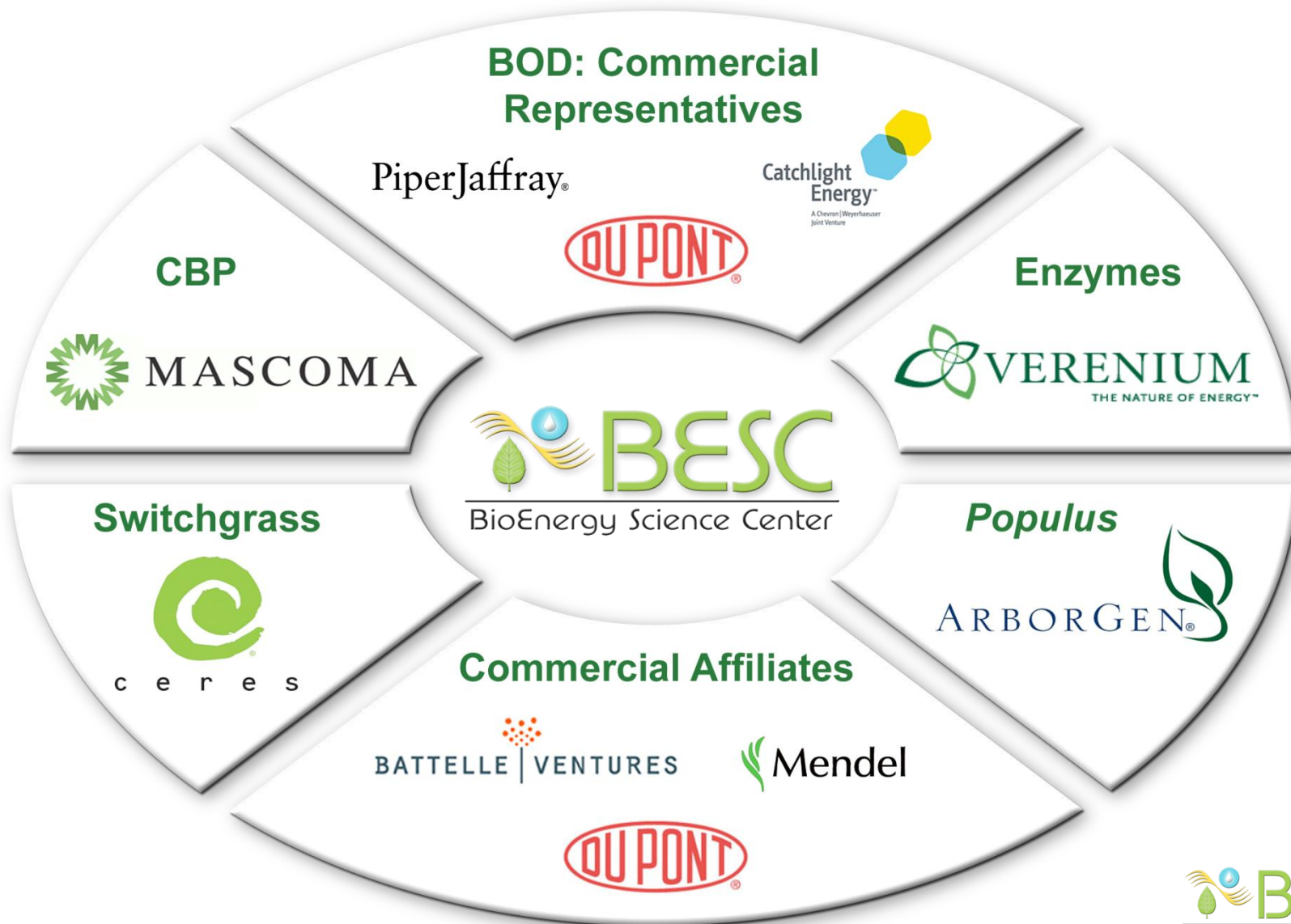


Influencing next generation of scientists

- National Geographic, The Jason Project, filmed and generated an educational module on bioenergy with BESC researchers
 - This module is available from www.jason.org
- Created an interactive biofuels outreach lesson for students in Grades 3-8
 - Piloted more than 220 lessons which reached over 6,000 students
 - Partnered with the Creative Discovery Museum
 - Available on www.bioenergycenter.org
- Piloted ten Biofuels Family Science Nights with an average attendance of 250 people each

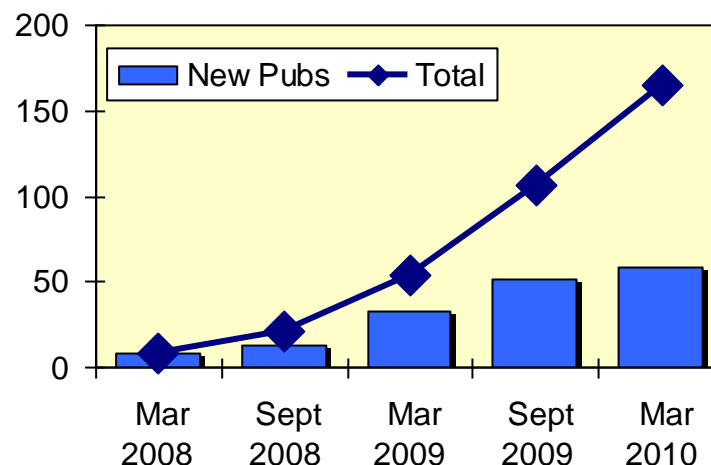


Industrial partners facilitate strategic commercialization



BESC Highlights 2008–August 2010

- 187 scientific publications
 - 33% of publications include external collaborators at non-BESC Institutions
 - Several publications in top tier Journals
- BESC publications have already been cited 495 times in peer-reviewed journals
- 24 invention disclosures filed
- National Geographic, The Jason Project, filmed and generated an educational module on bioenergy with BESC researchers
 - This module, *Operation: Infinite Potential*, won three 2010 CODiE awards for best instructional solution grades K-12
- Over 275 scientific presentations at meetings and conferences worldwide



Thank you



SCIENCE RETREAT JUNE 2010



BESC is a U.S. Department of Energy Bioenergy Research Center supported by the Office of Biological and Environmental Research in the DOE Office of Science

